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THE EARLY TRAINING OF SCIENTISTS

IT is a strange feature of the modern educational process that though children are born richly endowed with scientific instincts into a world which has gladly accepted a multitude of gifts from science, they encounter, from the cradle to the university, constant opposition to the education of these instincts.

The child is excellent raw-material for the making of the scientist. First of all, he is curiosity incarnate; he does not confine his attentions to those matters which adults consider practical, but tries to learn all he can about an environment which he finds brimming with interest. Moreover, he is an experimentalist, and the days are too short for the experiments he wishes to perform upon everything at hand, from the bric-a-bric to the patience of his elders. He relies upon experiment rather than upon authority for learning truth. Authoritative representations concerning the fragile qualities of glass, the taste of pepper or the temperature of a stove are to him but suggestions for experiments. Although his experimental technique is simple and his capacity for reasoning and theorizing are undeveloped, he has made a splendid beginning towards a scientific career.

In his further development, however, he meets with opposition at every turn. Many of his experiments earn punishment from his parents, who discourage his curiosity and even pervert the truth for their own ends. At school, book-learning is substituted for observation and experiment, and even when the topic is nature or science it is often taught in a very didactic way by a teacher who, though having taken many courses in pedagogy, may have but little appreciation of the spirit and method of science. At Sunday school he is likely to find a teacher who praises as religious virtue the

docile acceptance of dogmatic authority and to whom the term "doubt" is one of opprobium.

The repressive process, alas, does not end here, for we in the university who next take him in hand delight in giving him the impression that the subject has been thoroughly elucidated. We take little pains to help him to realize the existence of vast fields awaiting exploration. Moreover, we are so anxious to guard him from errors of fact that we announce in advance what he is expected to find in his experiments. He is told to mix solution A with solution B and "to note the red precipitate which is formed." The precipitate he gets may happen to be yellow, but he has learned by this time that it is safer to call it red in his note-book. Why quarrel with the instructor, it is wiser to give the answer he wants and keep him in a good humor.

I am convinced of the justice of the foregoing diatribe, as I have had an intimate acquaintance with the problem, not only as a child, a student and a parent, but, I must confess also, as a teacher. Indeed, so thoroughly convinced have we been in the department of chemistry of the University of California of the importance of giving the student, so far as we can, a real training in the scientific method and spirit, that we have taken great liberties with that most conservative of all university courses, the freshman course in general chemistry. So many have asked for information concerning our methods that I am encouraged to assume sufficient general interest to justify an exposition of our attempt at the solution of this important problem.

We have been inspired by the opportunity offered by a fundamental course to present science in such a way as, first, to win for scientific careers the keen-minded students who are repelled by the drudgery and memory work of the old-fashioned course in descriptive chemistry; and, second, to encourage the average student to adopt the scientific attitude towards his everyday problems, an attitude so necessary in combatting the superstition, prejudice, selfishness and dishonesty in the world of ordinary affairs.

Although the following paragraphs describe a course in chemistry, our aim in giving this course is not simply to teach chemistry, but through it to teach science. Whether the student proceeds to advanced work in chemistry or enters one of the numerous fields for which it is prerequisite, or even takes no further scientific studies, it is important for him to have scientific training. The medium for this training is with us chemistry, but other subjects can, of course, be taught with a similar purpose in view.

In order to attain these ends we have been convinced that the laboratory work must be the central feature of the course, and that it must involve the solution of problems rather than the mere performance of illustrative experiments. This makes the work harder and therefore more interesting. The doctrine that the interest of the pupil is to be gained through ease and practicality is an educational fallacy. The student belies this doctrine in his own practice. Football is difficult and impractical, but it arouses far more interest than dishwashing, which is both easy and practical.

The teaching of elementary chemistry has been slow to reflect the modern state of the science, which is no longer chiefly descriptive, but to a high degree mathematical and deductive. It has largely continued, in the language of Le Chatelier, to present "une énumération indéfine de petits faits particuliers: Formules de combinaisons, densités, couleurs, action de tel on tel corps, recette de preparation, etc." Laws and principles appear to the student as dykes intruding into the mass, but not fusing with it. While it is difficult and probably undesirable to abandon altogether the traditional method, we have sought to substitute for much of the purely informational material, a grasp of great principles such as the atomic, molecular, kinetic and ionic theories, the mass law, and the periodic system of the elements, and to make them not mere definitions, but tools to be used with intelligence and skill. It is of little use for the student to define the mass law unless he can actually use it in controlling a new chemical reaction. There is little point in committing the periodic table to memory unless he can apply it with assurance in predicting chemical behaviors.

We have been fortunate in being able to in-

clude general chemistry and qualitative analysis in one intensive course of two laboratory periods, two quiz periods, and two lectures per week throughout the year. It has thus been possible to minimize the usual break between these subjects and to develop systematically from the general principles of chemistry to their application in the problems of analysis. In the laboratory manual, written by Professor W. C. Bray with the assistance of Dr. W. M. Latimer, the effort has been to stimulate the student, through proper experiments; first, to gain a working conception of the atomic theory, the molecular theory and the behavior of gases. There follows next, a study of acids and bases and of titration, in order to develop and apply the idea of concentration. A further study of acids, bases and salts leads to the ionic theory. In this connection we have not considered it necessary to discuss an element at length before studying one of its compounds. Acetic acid, for example, is a quite familiar substance, whose acid properties may be investigated before studying organic chemistry, and it is not necessary to discuss sulfur, sulfur dioxide and the manufacture of sulfuric acid in order to do some laboratory work with the acid. There follow assignments on strong and weak acids and bases and the uses of indicators to measure the concentration of hydrogen ion; rapid reversible reactions and equilibrium; the reversibility of neutralization reactions, or hydrolysis; the properties of sodium, potassium and ammonium ions and the tests for sulfate and nitrate ions; the chemistry of calcium ion, developing solubility equilibria and the transformation and solution of precipitates; carbonic acid, carbonate and bicarbonate ions; the salts of copper, sulfur and zinc, which prepare the way for the study of complex ions, amphoteric hydroxides and the important reactions utilized in qualitative analysis.

Unknown solutions of increasing difficulty are introduced during this period, but more emphasis is placed upon the student devising methods of analysis than upon committing to memory and using the orthodox schemes, which few chemists ever use in actual practice without appropriate short-cut modifications. Oxidation and reduction reactions and electric cells are next introduced, followed by a study of ions whose separations involve oxidation and reduction.

The effort is made constantly to throw the student upon his own responsibility, especially in observing accurately and in drawing general conclusions from his experiments. There are numerous questions calling upon him to predict results of untried experiments.

The lecture work is organized to supplement closely the laboratory work and to contribute an element of stimulus and inspiration. The topics in the early part of the course are taken up in much the same order. When acids, bases and salts are introduced in the laboratory, the lectures take up the alkali metals followed by the alkaline earth metals. The chemistry of the metals is so much simpler than that of the non-metals that we have been more than satisfied by our abandonment of the usual order of presentation in which the halogens are introduced early in the course. An intensive study of the periodic system and its use in predicting and correlating not only physical properties but chemical characteristics as well, continues throughout the year with necessary interruptions from time to time by other topics.

A reference book has been written for the course in which the aim has been to present clearly and briefly the principles of chemistry. The topics have been arranged in convenient order for reference rather than as in the lectures. The program of the lectures can thus readily be altered from year to year to try experiments of instruction, and making it easier to avoid the stagnation so fatal to even the best of courses.

But though general principles are emphasized in the teaching, we feel that the final test should not be the statement of the theories but their application. In our examinations, therefore, we usually say little about theories and principles, asking the student rather now to prepare one salt from another; how to accelerate or retard given reactions; how to shift certain equilibria; how to dissolve various precipitates; whether he would expect a given acid to be

stronger or weaker than another, or a certain salt to be more hydrolyzed than another; what properties of substances make them useful for certain purposes.

The success with which the more intelligent students are able to answer such questions has convinced us of the efficacy of this form of instruction. The students seem also to grasp something of the enthusiasm and interest in the science of chemistry which turns some of them ultimately into capable research workers. We have noted with considerable satisfaction moreover, that even the more purely descriptive type of chemistry is rather readily learned. It is evident that the habit of correlating facts with each other and with theory has made the assimilation of the information comparatively easy.

In order to achieve its object such a course must have the advantage of contact with the more advanced work and the research carried on in the department, and must be taught by men interested in discovery. It has been our policy, therefore, for all members of the departmental staff to take part at more less frequent intervals not only in the weekly conferences of instructors, but also in the laboratory and quiz sections. This practice has been effective in unifying the purposes of all the departmental courses. The junior assistants are all candidates for the Ph. D. degree, and hence actively engaged in research. The better students are frequently invited to see the work these graduate assistants are carrying on in the research laboratory, which proves a source of considerable inspiration.

Thus beginning with students from the high school, many of whom have not had even high school chemistry (for we admit students if they have had high school physics and trigonometry), we are able to accomplish in a single intensive course what is ordinarily extended over two years; and by continuing the same intensive method in the more advanced courses, to prepare the student for serious research at the beginning of the senior year. The large proportion of students who go on into graduate work and the output of the laboratory in research are evidence of the rich fruit of the method. We are confident also that those students who have studied elementary chemistry as preparation for some allied science have received a far better training for their later work than a more purely informational course could afford.

JOEL H. HILDEBRAND

ARE IODIDES FOODS?

IT has been considered by some biologists and chemists that living matter originated in the sea and the elements of living matter correspond to those found in the sea water. We might look, therefore, to the composition of sea water for the elements we should expect to find in living matter. Sea water consists largely of H_2O and sodium chloride, and besides those the chief ingredients are magnesium, calcium, potassium and carbonates, sulphates and bromides, but there are also present the following elements in traces: ammonia, lithium, rubidium, cæsium, strontium, barium, manganese, zinc, iron, cobalt, nickel, lead, copper, silver, gold, radium, fluorine, iodine, nitrate, phosphate, silicate, aluminium, boron and arsenic. In searching for these substances in living tissue they have been found chiefly in marine organisms. However, chemists are finding them to a greater and greater extent in tissues of mammals. Damiens[1] finds bromine in a large number of animals and Gautier[2] finds iodine in quite a number of animals. We are familiar with the fact that fluorine is a regular constituent of bones and teeth and iodine of the thyroid gland. In experiments on the nutrition of animals, I have found it very convenient to feed them evaporated sea water and in this way insure a supply of all the rare elements. Cameron and Carmichael[3] have not observed any deleterious effect in feeding rather large doses of sodium iodide to white rats and rabbits. The use of sodium

[1] Damiens, A., *Comptes Rendus*, 1920, clvvi: 930. Damiens, A., *Bull. Soc. Chem. Biol.*, 1921, iii: 95.

[2] Gautier, A., *Comptes Rendus*, 1920, clxx: 261; 1899, cxxix: 66.

[3] Cameron and Carmichael, J., *Journal of Biological Chemistry*, 1920, xlv: 69.